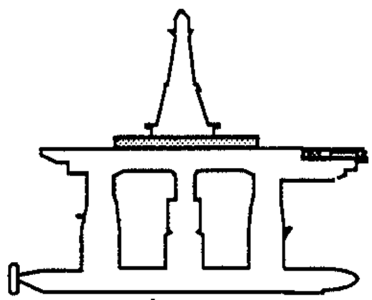
MANAGEMENT OF HUMAN ERROR IN OPERATIONS OF MARINE SYSTEMS



A Practical Human Error Taxonomy for Marine Related Casualties

by
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Report No. HOE-92-3
June, 1992

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1.0 INTRODUCTION

Approximately 65% of catastrophic marine related accidents (e.g. *Exxon Valdez* and *Piper Alpha*) are the result of compounded human and organizational errors (HOE) during operations. Yet to date there is no structured quantitative approach to assist engineers, operators, and regulators of marine systems to design human and organizational error (HOE) tolerant systems. No considerations have been established to include human and organizational errors as an integral part of the design, construction, and operation of marine systems [Bea & Moore, 1991].

Examination of HOE in tanker and offshore operations has been limited by incomplete and non-standardized data in which to formulate risk analyses [Bea & Moore, 1991; Marton & Purtell, 1990; Laroque & Mudan, 1982]. In order to construct quantitative models for HOE analysis of marine systems, it is important to establish a comprehensive, standardized, validated and commonly used error taxonomy (classification) to identify HOE factors in the casualty process [Marton & Purtell, 1990]. There exists no standardized, hierarchically organized, concept or format for identifying human factor casualty data to identify and link underlying, direct, and compounding causes that shape human behaviors and actions responsible for accident sequences.

This report establishes (1) an organizational and classification framework for systematically identifying and characterizing the various types of marine related human and organizational errors and (2) uses case study examples to determine the effects of human and organizational errors in accident sequences. The taxonomy classifies human errors into individual, organizational, regulatory, and system contributors to accident scenarios. The taxonomy is used to establish the contributing HOE's related to the *Exxon Valdez* grounding and the *Piper Alpha* disaster.

2.0 BACKGROUND

Establishing the HOE taxonomy is the second of five tasks proposed by the Joint Industry Project *Management of Human Error in Operations of Marine Systems.* The purpose of these tasks are to:

(1) Identify, obtain and analyze well documented case histories and databases of tanker and offshore platform accidents whose root causes are founded in HOE.

(2) Develop an organizational classification framework for systematically identifying and characterizing the various types of HOE.

(3) Develop general analytical frameworks based on real-life case histories to characterize how the HOE's interact to cause accidents. The case histories are post-mortem studies (*Exxon Valdez* and *Piper Alpha* disasters) and existing operations (tanker loading & discharge and offshore crane operations).

(4) Formulate quantitative analyses for the case histories based on probabilistic risk analysis (PRA) procedures using influence diagrams. Perform quantitative analyses to verify that the analyses can reproduce the results and implications from the case histories and general statistics of marine accidents.

(5) Investigate the effectiveness of various alternatives to reduce the incidence and effects of HOE. Evaluate the costs and benefits in terms of risk reduction (products of likelihood and consequences).

In the report, *Human and Organizational Error in Marine Systems: A Review of Existing Taxonomies and Databases* [Moore, 1991], a number of marine related HOE taxonomies, databases, and marine casualty reports were examined in an effort to establish a basis for developing practical error classifications [Marton & Purtell, 1990; Bea & Paté-Cornell, 1989; Veritec, 1988; Veritec, 1984; Panel on Human Error in Merchant Marine Safety, 1976]. Nevertheless, as concluded by Marton & Purtell (1990), there currently exists:

(1) no comprehensive standardized, validated and commonly accepted taxonomy of human factors to adequately identify human factors involved in the casualty process;

(2) no standardized, hierarchically organized, concept or format for identifying human factor casualty data in order to identify and correlate direct causes of such a casualty to the underlying and contributing factors that shape the behaviors responsible for error and accident events; and,

(3) no commonly accepted data collection concepts or methodology that assist marine casualty investigators to accurately detect, describe and record the key human error elements correlated with marine casualties.

These limitations in examining human factors for marine casualties have led to the development of the *Annotated Human Factors Taxonomy* (AHFT) to be used by United States Coast Guard investigators [Dynamics Research Corporation, 1989]. The AHFT is the basis for the HOE project taxonomy due to its general applicability to the marine industry. Yet, the AHFT is limited in some aspects and is supplemented by the addition of several key measures of human and organizational behavior and performance including violations, commitments to safety, and allocations of safety resources.

2.1 Issues in establishing an HOE taxonomy

One of the keys to the development of an effective taxonomy is to determine the goals and preferences of the model user. For example, tanker or offshore platform operators may wish to establish error classifications and models which enable them to focus on specific areas to allocate limited resources in an efficient manner. These goals and preferences may be established in the taxonomy to examine the effects of the operating alternatives weighing safety, economic, and production costs and benefits as the driving force. On the other hand, regulators and policy makers may wish to establish both economic and social costs of specific tanker and offshore operations. In short, the taxonomies and models would vary to project the preferences of the user in examining costs and benefits of these operations.

The complexity of the taxonomy must be weighed against the time, available resources, goals and preferences of the user. A primary problem in classifying errors is striking a balance between a general error taxonomy addressing general adaptive processes or basic error tendencies or highly detailed examinations of specific error forms [Reason, 1990]. For example, the user may wish to establish a general framework model with only limited detail and spend more time on analysis and examining the effects of sensitivity and uncertainty in the model. Yet another individual or group may wish to develop a meticulously detailed error taxonomy and model formulation at a substantial cost in time and resources. This preference would allow the user to examine finely detailed aspects of human performance or limit the amount of ambiguity and uncertainty in the taxonomy and model formulation.

The goal of establishing this taxonomy is to develop an organizational classification framework for systematically identifying and characterizing the various types of marine related human and organizational errors. The taxonomy should be commonly agreed upon and practical for engineers, regulators and decision makers. In addition, the taxonomy should be simple enough to use for a range of experience and expertise levels of the user, yet robust and detailed to allow users to adequately model the marine operating system.

2.2 Characterizing error and failure factors

As stated by Reason (1992), effective safety management can only be obtained by having relevant up-to-date information on the reliability of the operating system. The status of the factors that influence reliability of a system are continually in a state of flux as a result of changes in economic conditions, management, organizational culture, variability in human performance, changes in technologies, degradation of operating systems, and variability in environmental conditions. Like most industries with low probability - high consequence accidents (e.g. nuclear power, air traffic control, aircraft carrier flight operations, etc.), the tanker and offshore industries operate with dynamic safety states varying in time. These *intrinsic safety states* are dependent upon measures of human, organizational, and system performance as shown in Figure 1. The safety state of the system can be gauged for each factor. For example, the "design" of the system may be simple and robust or complex and weak. Most systems operate between the either extreme factors range somewhere between

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Factor	Gauging system	
DESIGN	complex weak link	simple robust
HARDWARE/ SOFTWARE	low quality	high quality
OPERATIONS	unplanned careless	planned careful
MAINTENANCE	none reactive	thorough proactive
TRAINING	none undisciplined	thorough disciplined
CRISIS MANAGEMENT	unplanned untrained	planned trained
VIOLATIONS	many frequent	few infrequent
VERIFICATION/ POLICING	none condone	intensive proactive
ORGANIZATION	product oriented undisciplined	process oriented disciplined
COMMUNICATION	stiffled perfunctory	intense effective
COMMITTMENT	low level casual	high level devoted
RESOURCES	none	extensive

Figure 1: Operating system profile

the two extreme ends. Each of the factors must be assessed to determine the "temperature" (reliability) of the system.

The basis of safety information systems lie in the development of a taxonomy to identify human factors contributing to a potential accident scenario. Figure 2 demonstrates five elements which relate to accident causation [Reason, 1992]. Defenses are placed in the system to reduce the chances of accidents or incidents. The defenses may be systems (e.g. redundancy, high load capacity) or operational (e.g. safety programs, regulations). Human failures can be classed into *types* and *tokens*. Failure types are those which are founded in organizational, management, and regulatory culture, policies and procedures. The failure types can be further distinguished into *source* and *functional* types. Source type failures are decisions made at the strategic level of the organization. Functional types failures are made at the line management level where strategic errors manifest into functional form. Tokens are subdivided into *condition* and *unsafe acts*. Condition tokens are dependent upon psychological or conditional states of the operators or system which lead to unsafe acts at the operator crew level. Unsafe act tokens are categorized as slips, lapses, mistakes or violations.

In examining the effects of human errors in marine systems the most available and used sources of safety information are accident and incident reports. However, accident and incident reports do not always do not always capture important underlying causes to accidents and incidents [Moore, 1991; Marton & Purtell, 1990; Laroque & Mudan, 1982; Panel on Human Error in Merchant Marine Safety, 1976]. Accident reports are currently being used to examine human, organizational and system errors leading to catastrophic consequences in tanker and offshore platform operations [Paté-Cornell, 1992; Roberts & Moore, 1992]. However, current changes in operational procedures resulting from accident analyses tend to lead to ad hoc human and organizational error management alternatives. For example, the Oil Pollution Act of 1990 (OPA 90) requires all tanker new builds to be double-hulled to reduce the chances of hydrocarbon spills in the event of collision or grounding. The decrease in vessel capacities (as much as 40%) result in the need for more vessels for transport to keep pace with demand. This can lead to higher vessel traffic and possibly increase probability of vessel collisions [Bea & Moore, 1992].

A logical progression in gathering system safety information is to examine unsafe act errors and violations which directly lead to accidents and incidents. Unlike the commercial aviation industry, there is no established reporting system in the marine industry to gather information on unsafe act errors and violations. The commercial aviation industry maintains the *Aviation Safety Reporting System* (ASRS) which receives, processes, and analyzes voluntarily submitted aviation incident reports by pilots, air traffic controllers and other industry sources. Efforts to develop a similar system for the marine industry have been in vain. Unsafe acts in the marine industry have generally been kept in confidence by the operators. Violations result from issues of motivation, individual and management attitudes and cultures which are founded at higher levels in the organization. For example, at the time of the *Piper Alpha* disaster, the platform had been conducting critical maintenance on a condensate pump system and simultaneously producing at the highest possible level which led to a succession of explosions and fires killing 167 men and destroying the platform. Yet one of the roots of the problem was founded in the organizations which allowed the simultaneous maintenance and production to maintain production schedules [Paté-Cornell, 1992].

The next level in the safety information system scheme are the condition tokens. These are psychological and situational precursors to accident scenarios. These are factors which

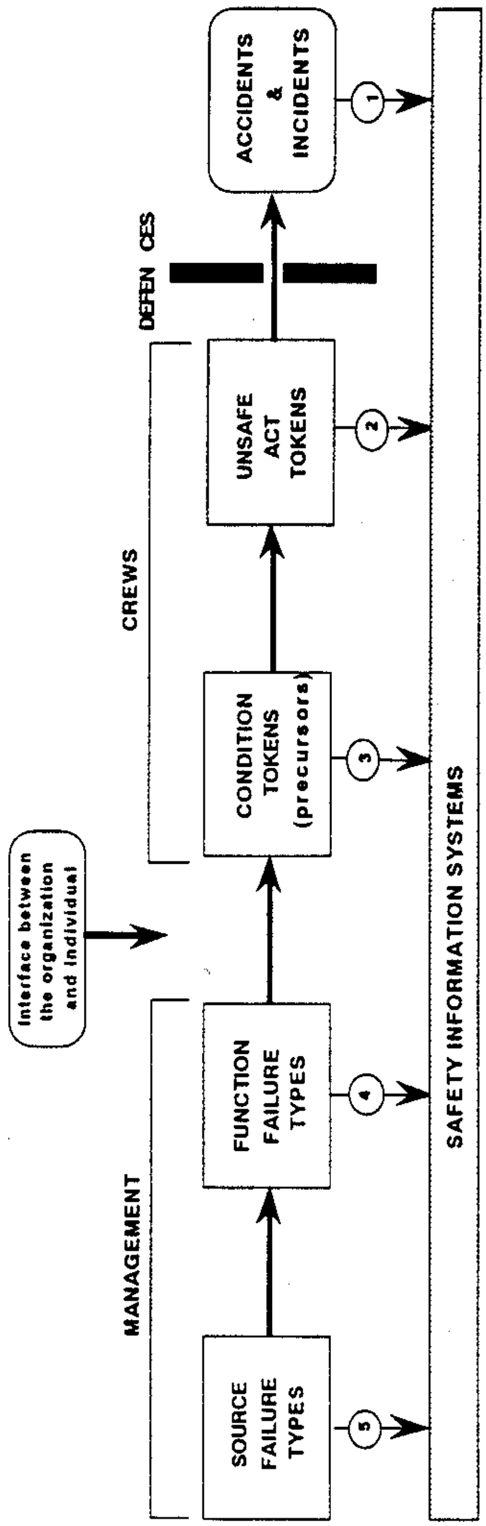

Figure 2: The basic elements of safety information system as they relate to the type-to-token stages involved in accident causation.

contribute to unsafe acts such as hazardous working environments, job design, and inadequate training. Each of these error tokens root causes are found in critical underlying contributing errors types. For example, the day before the *Piper Alpha* disaster, the Offshore Installation Manager (OIM) had left the platform. Instead of bringing aboard another qualified OIM, there were temporary promotions of personnel to compensate for the loss of the OIM. The acting OIM was unable to coordinate an evacuation during the crisis leading to his death and 83 other men in the accommodations unit [United Kingdom Department of Energy, 1990]. This is an example of a situational condition which compounded the catastrophic loss of life and platform. The acting OIM was inadequately trained for the job though the underlying contributing causes can be directed at the management level for not maintaining qualified personnel during critical operations.

Assessing safety information of functional failure types begins to address the "intrinsic safety health of an organization" [Reason, 1992]. For example, general failure types can be categorized as: inadequacies in operating procedures and conditions, system defects and inadequate defenses, communication failures, poor maintenance, design failures, and so on. This is the heart of where the safety state of the system can be gauged as mentioned above (see Figure 1).

Finally, addressing source failure types looks towards long-term safety goals of the organization. This is can be directed at top-level management's commitments to safety, competence in addressing problems and cognizance of the problem nature. Though there is no standardized form to assess these issues, Reason (1992) has categorized the states of organizational behavior toward safety practices:

(1) *Pathological*: Safety systems are at minimum industry standards, no top-level management commitments toward safety goals.

(2) *Incipient reactivity*: Staying just one step ahead of regulations and showing signs of concern for accident trends.

(3) *Worried-reactive*: Concern about continual trends in close calls, incidents and accidents in its operations.

(4) *Repair-routine*: Reasonable sensitivity to past and potential future accident events, safety data collected (accidents and incidents) and remedial safety measures implemented on a local level.

(5) *Conservative-calculative*: Conduct a range of auditing techniques and workplace safety measures. Concerned with "techno-fixing" safety measures for humans and operating systems (i.e. better hardware and ergonomics).

(6) *Incipient proactivity*: Moving away from engineering fixes and acknowledge the role of organizational culture, policy, and procedures in the reliability of the operating system and actively searching for better human error management alternatives.

(7) *Generative-proactive*: Large number of proactive measures in place, top level commitments to safety, safety measures continually being assessed and updated, and a lack of complacency among management.

3.0 BASIS FOR MARINE HOE TAXONOMY

In forming the human and organizational error taxonomy for marine systems, it is important to capture both error types and tokens. Examining marine operations and potential accident scenarios requires addressing the scenario specific problems (error tokens) and their underlying causes (error types) to evaluate error management alternatives. Figure 3 shows the primary sources of accident data information acquired in the developments of the HOE taxonomy. The HOE project taxonomy is a culmination of error classifications.

3.1 Case Histories and Database Sources for Taxonomy Development

In August of 1990, we initiated an extensive search for offshore platform and tanker accident investigation reports and casualty databases. This information has been obtained from a number of sources.

1.) The USCG has supplied 30 written accident reports for tanker and mobile offshore drilling units (MODU's) casualties dated from 1979 to 1990. In addition, they have supplied the marine casualty data base (CASMAIN) which include 58,934 marine casualties dated through 1990.

2.) The National Transportation Safety Board (NTSB) has supplied 60 written accident reports dating from 1980 to the present. The NTSB updates us with important accident reports as they become available.

3.) The Minerals Management Service (MMS) has supplied us with 42 written accident reports dating from 1979 to 1989 and offshore continental shelf accidents associated with oil and gas between 1956 and 1986. In addition, reports on risk analysis for offshore welding and crane accidents have been obtained.

4.) Independent accident reports and inquiries have been obtained for the *Piper Alpha* and disaster, including the Lord Cullen and Petrie reports. These reports have information on potential accident sequences, pre and post disaster design, operations, and regulations offshore. We have found *Piper Alpha* to be the most well documented offshore accident, these reports are to form the basis for Task 3 of the study which is discussed below.

5.) Approximately 7500 records of offshore casualty data has been obtained from WOAD up through 1988. Data consists primarily of events and not related causes.

6.) Bureau Veritas has offered access to the Institut Francais Du Petrole's (IFP) database for offshore platform (850 accidents covering 1955-1988) and tanker accidents (1,150 accidents since 1955).

7.) Offshore reliability data (OREDA) provides reliability information on safety, process, electrical, utility and crane systems, and drilling equipment.

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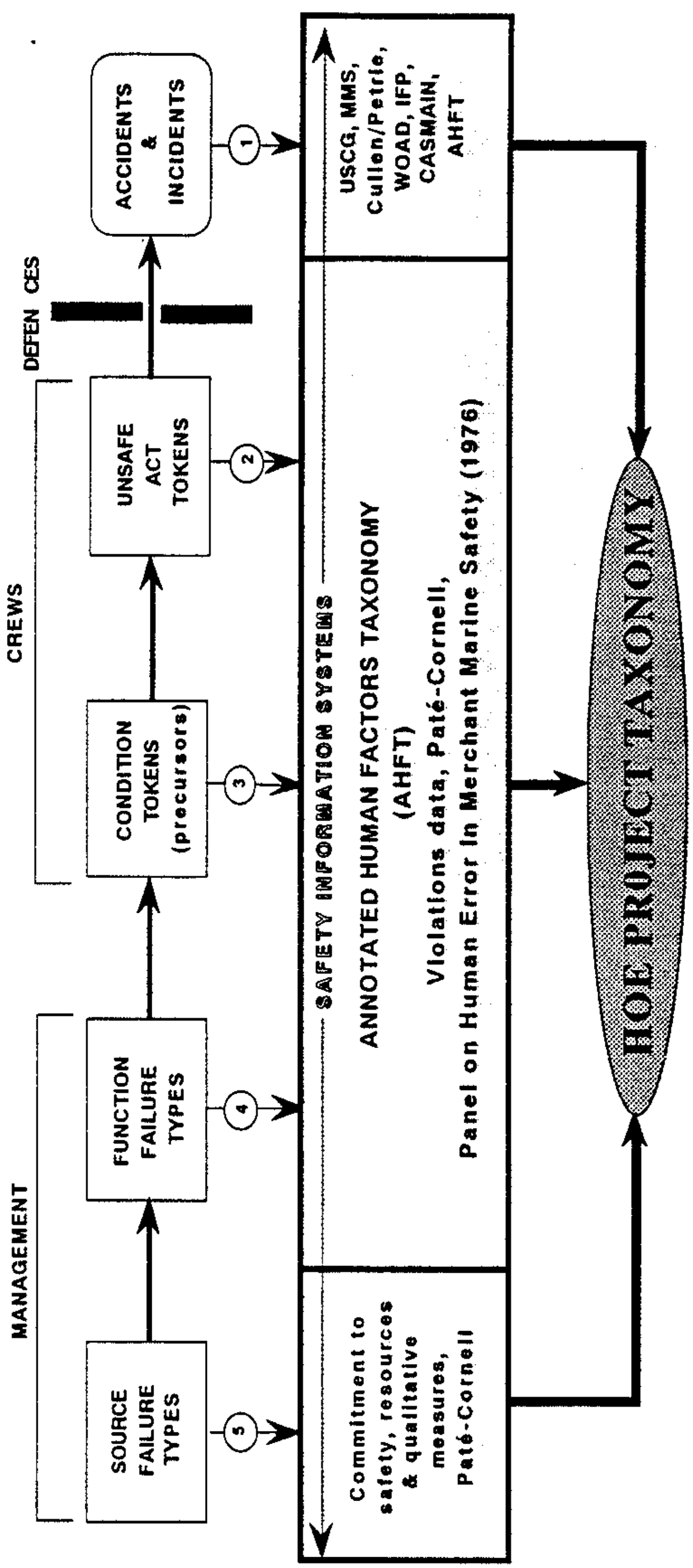

Figure 3: Sources of information for marine HOE taxonoomy developments

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3.2 Current Status of Marine Casualty Taxonomies

3.2.1 USCG CASMAIN marine casualty database

CASMAIN is currently the United States Coast Guard's primary source of marine casualty data. Though CASMAIN is primarily single dimensional and task oriented and lack in complex interaction of human errors, it had established a basic taxonomy of human and organizational factors [Dynamic Research Corporation, 1989] and are listed in Table I.

Table I: CASMAIN human factor casualty causes

**Bypass available safety devices*	**Inattention to duty*
**Intoxication (alcohol/drugs)*	**Calculated risk*
**Carelessness*	**Error in judgment*
**Lack of knowledge*	**Lack of training*
**Lack of experience*	**Operator error*
**Fatigue*	**Smoking*
**Open flame*	**Stress*
**Physical impairment*	**Psychological impairment*
**Failed to comply with rules, regulations or procedures*	**Inadequate supervision*
**Improper casualty control program*	**Improper safety precautions*
**Failed to account for current/weather*	**Failed to account for tide*
**Failed to use available navigation equipment*	**Failure to ascertain position*
**Failed to use charts & publications*	**Failed to use radiotelephone*
**Relied of floating aid to navigation*	**Failed to yield right of way*
**Failed to establish passing agreement*	**Failed to keep to right of channel*
**Failed to proceed at safe speed*	**Failed to stop*
**Failed to keep proper lookout*	**Improper/faulty lights/shapes*
**Improper/missing whistle signal*	**Improper maintenance*
**Used defective equipment*	**Design criteria exceeded*
**Service condition exceeded*	**Improper loading*
**Preventative maintenance not done*	**Improper cargo storage*
**Improper securing/rigging*	**Improper mooring/towing*
**Inadequate fire fighting equipment*	**Inadequate lifesaving equipment*
**Inadequate controls*	**Inadequate displays*
**Inadequate statutory/regulation requirements*	**Inadequate owner/operator*
**Inadequate owner/operator safety program*	**Inadequate manning*

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3.2.2 World Offshore Data Bank (WOAD)

WOAD is the world's largest databank of offshore accidents. Reports issued by Veritec state the need to focus on worldwide operational safety and human factors, the database is limited to documenting accident events resulting from HOE [Bekkevold, E., Fagerjord, O., Berge, M., & Funnemark, 1990]. Yet the database is similar in nature to that of CASMAIN which provides little information on the detailed chain of human error causes to accident scenarios. WOAD uses the following fields of human related errors:

Unknown — *Unsafe act*

- *Unknown*
- *Improper design*
- *Unsafe procedure* (jury rigged system)
- *Collision with vessel passing by*
- *Smoke/match ignition*
- *Safety system malfunction*
- *Unsafe act*
- *Improper equipment used*
- *Sabotage*
- *Open flame*
- *Welding/cutting torch ignition*
- *Other*

3.2.3 Marine Board taxonomy for marine casualties

The Maritime Transportation Research Board (MTRB) conducted a five year study on merchant marine safety entitled *Human Error in Merchant Marine Safety* (1976). The objective of the study was to determine the causes of marine casualties resulting from human errors. The MTRB panel concluded that there were 14 human factors which led to marine casualties or near casualties. These factors include:

(1) *Inattention*: lack of full vigilance to duties and responsibilities assigned.

(2) *Ambiguous pilot-master relationship*: confusion in authority and responsibility.

(3) *Inefficient bridge design*: poor instrumentation and control stations.

(4) *Poor operational procedures*: failure of deck and engine watchstands to observe consistent operating standards.

(5) *Poor physical fitness.*

(6) *Poor eyesight.*

(7) *Excessive fatigue.*

(8) *Excessive alcohol use.*

(9) *Excessive personnel turnover.*

(10) *High level of calculated risk.*

(11) *Inadequate lights and markers: particularly for vessel navigation purposes.*

(12) *Misuse of radar.* Misuse or misinterpretation of radar equipment.

(13) *Uncertain use of sound signals*: general failure to employ sound signals as required for rules of the road.

(14) *Inadequacies of the rules of the road*: when rules are considered to be the source of, rather than the countermeasures to human error casualties.

These conclusions were based upon an intensive literature search as well as 359 in depth interviews distributed to pilots, masters, deck officers, chief engineers, engineering officers, tug and harbor personnel.

In addition to these human factors, the panel concluded there is an inadequate database to maintain statistics on marine casualties and had recommended the development of such a database by the USCG. The MTRB panel also suggested recommendations to address the 14 human factors listed above.

Through examination of the questionnaires and literature search, the MTRB panel defined 13 types of human errors they believed to be detrimental to safe marine operations:

**Panic or shock*

**Drunkenness or drug influence*

**Inattention*

**Anxiety*

**Negative transfer of training*

**Ignorance*

**Fear*

**Sickness*

**Confusion*

**Incompetence*

**Fatigue or drowsiness*

**Negligence*

**Calculated risk*

3.2.4 Organizational error taxonomy for platform casualty analysis

Patè-Cornell & Bea (1989) have suggested an organizational error taxonomy for design, construction, and operations of offshore platforms defining organizational errors as: (1) individual errors that are "grounded" in the organizational structure, and (2) legitimate and rational decisions by the individual which are in variance with the standards of the organization. This taxonomy of operator errors can be used to relate individual errors with those rooted in the organizational structure. Previous analysis of organizational errors in design, construction and operations of platforms have resulted in quantitative assessments of alternativews to improve reliability through organizational modifications.

Organizational errors can be the result of three major sources: (1) human limitations (e.g. fatigue, seasickness, etc.), (2) lack of communication and transfer of relevant information to decision makers at appropriate management levels, and (3) incentive problems resulting from incompatibility of goals and preferences between various levels of management and specific actors.

Figure 4 shows the taxonomy developed to address organizational errors. The taxonomy distinguishes errors between *gross errors* and *errors in judgment.* Gross errors are those resulting from a lack of knowledge, understanding, and the inability to respond under various circumstance. Gross errors are also errors in which there is little controversy or ambiguity and the individual would take notice of the error if brought to his attention. Errors in judgment are interpretations of available information which may be incomplete or uncertain and decisions are ambiguous in nature.

Gross errors can be further distinguished into communication and cognitive problems and human limitations. Communication errors are those where information is not available to the decision makers at specific levels because the information may not have been gathered or the proper communication channels do not exist between involved parties. In addition, the goals may not be communicated to illicit proper actions.

Cognitive problems are divided into accidental slips, wrong models, and genuine ignorance. Accidental slips are those errors resulting from such aspects as work overloads, stress and improper job design. An individual in the organization may firmly believe in a wrong model because of errors in interpreting incomplete information. In the third case, the individual may be unable or unwilling to acquire additional information and thus is genuinely ignorant to the situation. Human limitations can be the result of either physical or psychological factors which can be the result of inadequate hiring practices or bad individual job design.

Errors of judgment can be distinguished into bad individual judgment and good individual judgment. Bad individual judgment can be in operational behavior, misuse of information and goals of the organization. Errors of judgment may also occur when inadequate procedures and organizational structures lead to rational decisions which are at odds with the overall objectives of the organization.

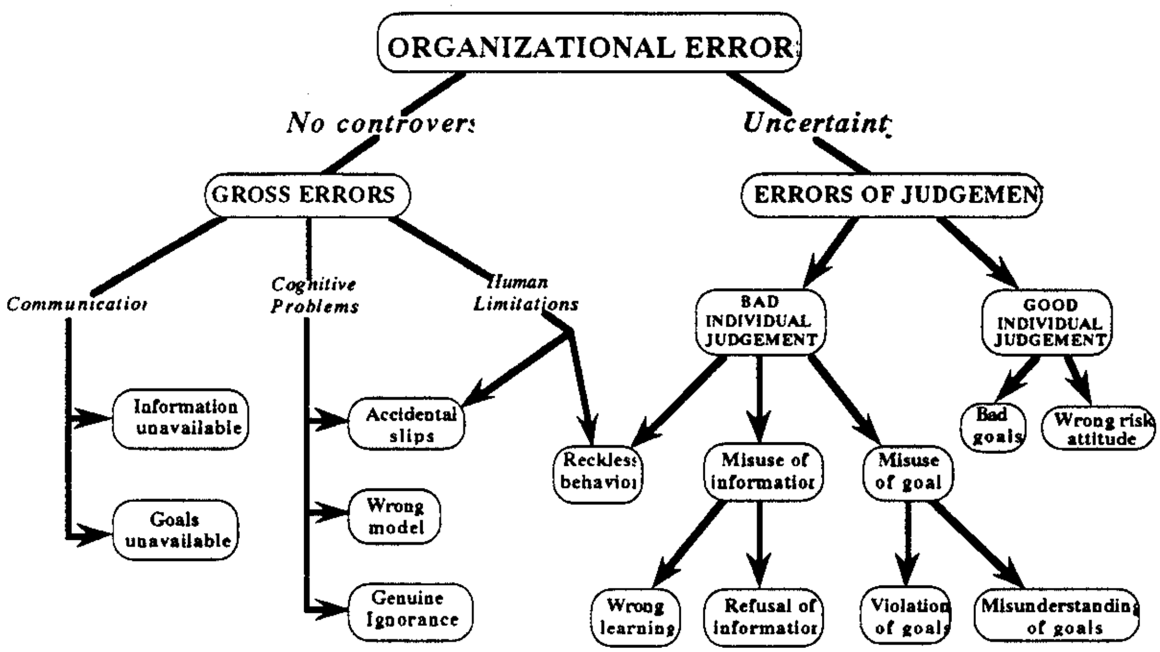

Figure 4: A taxonomy of organizational errors [Paté-Cornell & Bea, 1989]

4.0 HUMAN AND ORGANIZATIONAL ERROR TAXONOMY

In the framework of error types and tokens discussed by Reason (1992), the taxonomies mentioned above primarily address error tokens. The HOE taxonomy will incorporate both error types and tokens. Error tokens provide a basis for determining the underlying error types. For example, insufficient tanker manning (an error token) can be contributed to the commitments to safety by both the operator and the regulator (error type). The current status of accident data primarily focuses on active (initiating) errors with little or no information on underlying or contributing error types.

The development of HOE model framework analyses are through the examination of post-mortem studies (e.g. *Exxon Valdez* and *Piper Alpha*), and case studies (tanker loading & discharge and platform crane operations). Analysis of post-mortem studies can directly yield the error tokens (e.g. fatigue, lack of training or judgment error) and through further analysis of error types (e.g. organizational communication and top-level commitments to safety) can be determined and error management alternatives evaluated. Similar is true for case study examples.

The remainder of the chapter is dedicated to the error taxonomy and how it will be categorized for HOE framework modeling. The AHFT is the basis for the HOE project taxonomy due to its general acceptance in the marine industry. Yet, the AHFT is limited in some aspects and is supplemented by the addition of several key measures of human and organizational behavior and performance including violations, commitments to safety, and allocations of safety resources.

4.1 Basis for HOE Taxonomy

The primary basis for the HOE taxonomy is the USCG *Annotated Human Factors Taxonomy* (AHFT). The AHFT was developed to improve upon the CASMAIN database to correlate underlying human factors contributing to marine casualties. The AHFT has been reviewed by regulators, operators, human factors experts and has gone through seven revisions.

The AHFT will become an important tool of the USCG marine casualty investigation procedures. Figure 5 demonstrates the format for USCG marine casualty investigations. Stage I is an identification of prior and current ship operational, equipment, and environmental characteristics and status. This stage is an analysis of the characteristics of the vessel operations with regard to operating procedure, equipment and technology, and personnel. Stage II identifies the personnel and task performance requirements and constraints. This is an assessment of the current level of performance potential to operate the system. Stage III is a determination of adequacy of performance. In other words, were the personnel and/or task performance requirements sufficient to avoid the accident? Stage IV is the identification of the human factors in the accident sequence given the information provided in Stages I-III. The contributions of human factors are specifically identified and described in Stage V. The causes are distinguished into contributing and underlying causes, direct or casualty initiating errors, and compounding errors. Stage VI is the identification of corrective actions (applied safety management).

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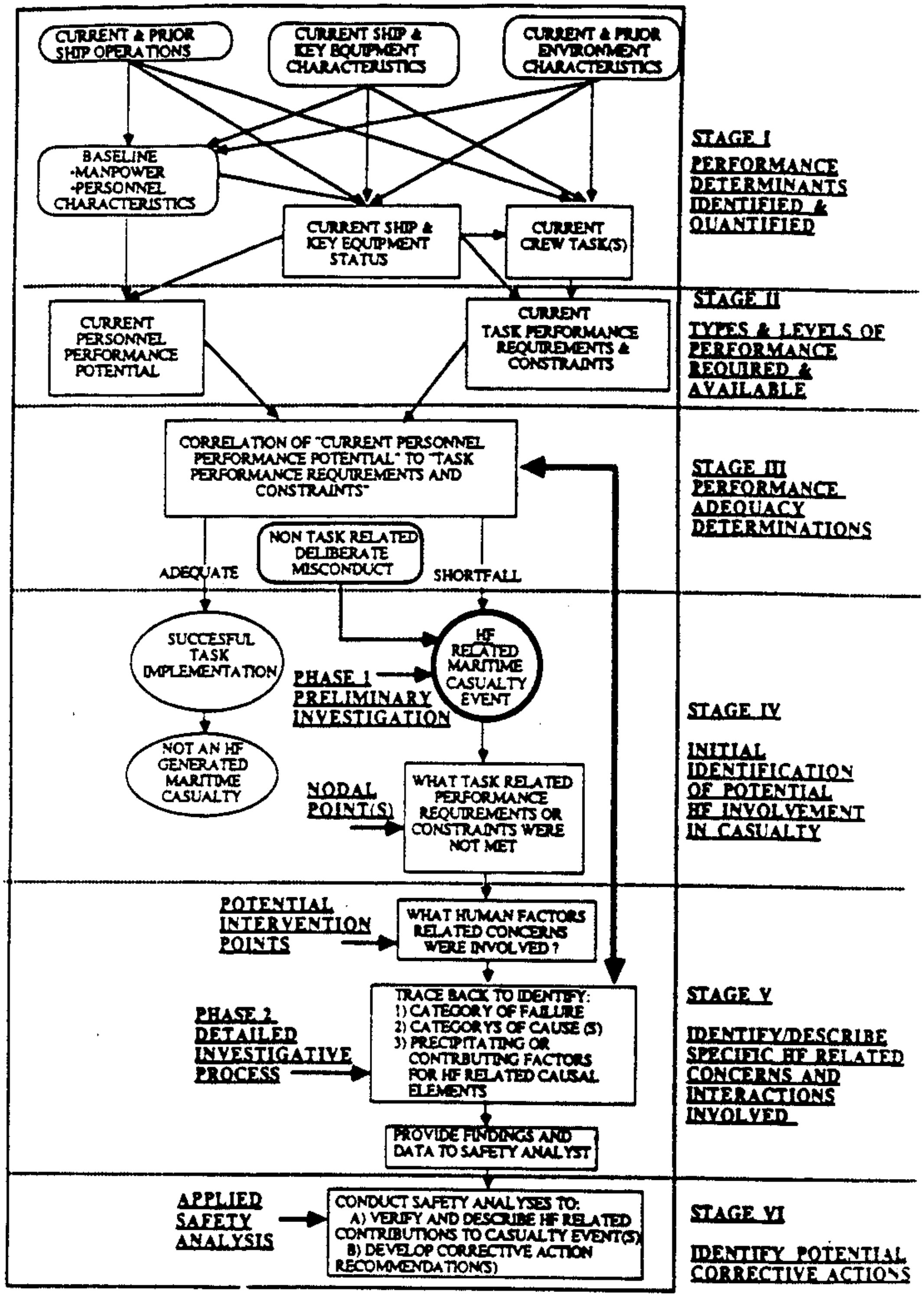

Figure 5: Human factor related marine casualty investigation and safety development model

As shown in Figure 6 general breakdown of the AHFT distinguishes errors into states and actions. The states include incentives and motivation of the organization and operating crews, the operating environment and situations, as well as information and communications. The error actions include the include active errors initiated by the operating crews. These are lapses (memory failures) and (attention failures) slips, mistakes (rule-based mistakes), violations (routine violations) of which all can be categorized as unsafe acts [Reason, 1992].

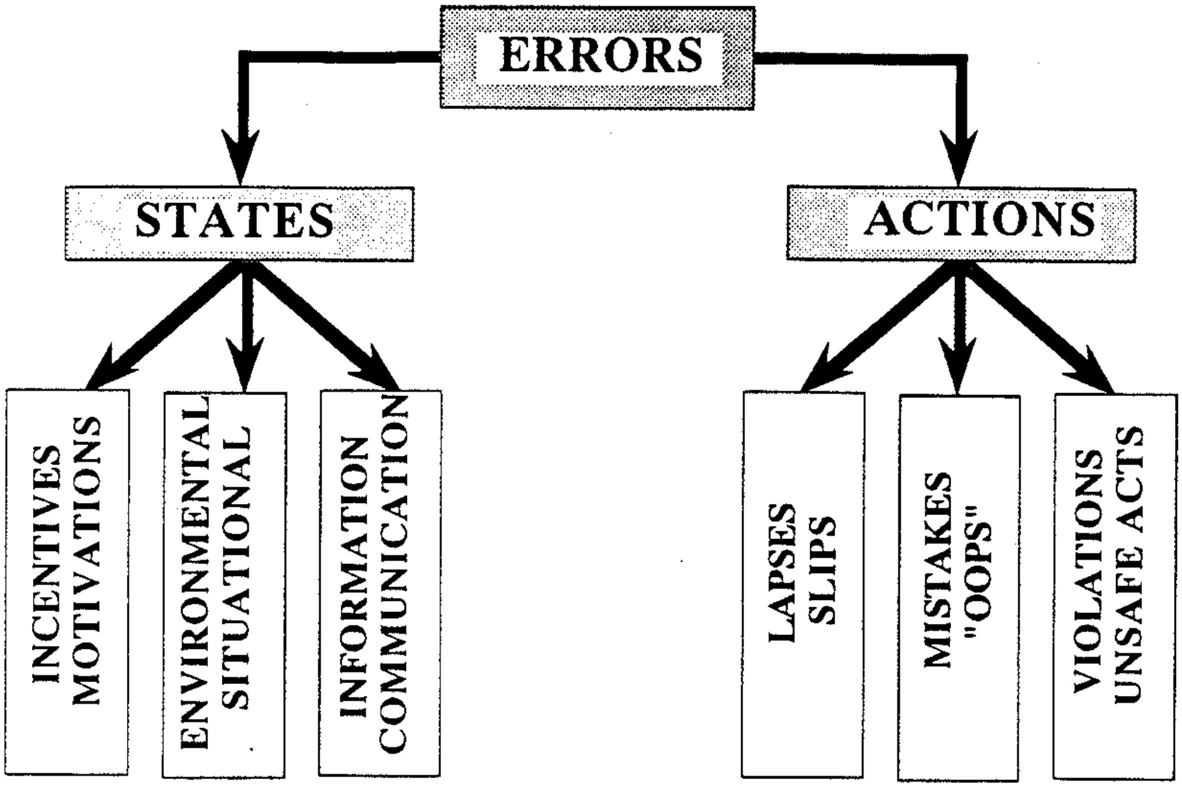

Figure 6: General AHFT error breakdown

The application of the AHFT is in Stages IV-V in the casualty analysis. Human error related casualty causes are categorized into [Dynamic Research Corporation, 1989]:

(1) *Training & experience*: This refers to "the effects or impacts generated by concerns associated with inadequacies in training or experience of the ships permanent or transient crew members or that of port personnel associated with the loading, unloading, repair, or maintenance of the ship."

(2) *Behavioral*: This section concerns "associated with psychological, emotional stressor and motivationally related behavioral attributes or concerns."

(3) *Human factors*: These topics include "all concerns associated with human factor or human engineering related to developing and sustaining the facility, equipment, software and operational interface designs needed to support the effective performance of the ships crew during normal, degraded or emergency

operations and assure the health, safety, and well being of the ship's crew and passengers."

(4) *Management & administration*: This includes "all concerns associated with administrative and management practices that impact manpower, personnel or crew procedural or performance requirements during normal, degraded or emergency mode operations afloat or in port."

(5) *Information/communication*: This section includes "concerns associated to any, or with any, human factor related aspect or type of transfer of significant information between crew members, ship to ship and ship to shore stations that can cause or increase the severity of a marine casualty."

(6) *Bio-medical*: This section "covers concerns any biological, physiological or medical factor capable of directly effecting the crews physical health or well being so that their ability to successfully perform their required task and/or functions, maintain good health, and/or survive is degraded to unacceptable levels."

(7) *Environment*: This heading "covers external environmental factors capable of directly or indirectly degrading a human factors related concern effecting the physical, functional, operational or safety status or potential of a ship, its permanent or transient crew, passengers, or cargo in a manner or to a level that could lead to a marine casualty."

(8) *Hardware/software*: This covers "failures or shortfalls effecting a human factors related concern generated by hardware or software factors in any area of the marine operational environment that can directly or indirectly cause or increase the severity of a marine casualty."

Under each of the above error categorizations are several acronyms to describe the specific human factor. Yet the AHFT fails to capture some key elements in the human error induced casualty process:

(1) *Violations*: The AHFT makes no direct inference to violations of either the front-line operating crews, front-line management, or organization. The USCG currently maintains a separate database for violations.

(2) *Commitment to safety*: No mention is made of the influence of top-level management to the safety of the operation. Commitment to safety has two primary components: motivational and resources. Though commitment to safety is not sufficient for operational reliability. There must be a competence of personnel (see "resources" below) and a cognizance of the potential hazards of the operation (Reason, 1992).

(3) *Resources*: The commitment of resources is not only a factor of money but expertise and caliber of personnel from top-level management to front-line operators.

4.2 Basic HOE Taxonomy

The following is a presentation of the general marine operations human and organizational error classification and their descriptions. As shown in Figure 7, the taxonomy sources lead to the error classification.

(1) *Commitment to safety*: The level of commitment of available resources (money and expertise) and cognizance of potential problems to the safety of the operational system from top-level managers to the front-line operating crews. Yet, there is a distinction between commitments to safety and the resources applied to the system. There can be a commitment to safety, but insufficient resources, expertise and cognizance to obtain higher levels of safety. Commitments to safety encompasses human tasks and performance, organizations and regulatory bodies.

(2) *Resources*: Resources pertain to money and expertise to heighten operational safety. There may be the sufficient resources, yet little or no commitment to safety at various levels of the organization or by front-line crews. Commitments of resources encompasses human tasks and performance, organizations and regulatory bodies.

(3) *Human/system interface*: Encompasses failures and shortfalls of human action resulting from inaccurate or insufficient information or response of control systems and control system display. Human/system interface problems will be addressed particularly between the front line operators and the system during normal and crisis situations.

(4) *Knowledge/experience/training*: Pertains to human or organizational failures and shortfalls resulting from insufficient or improper knowledge, experience, or training of the system under normal or extreme operating conditions. Knowledge, experience, and training are particular issues concerning the organizations, management, and front-line operating crews responsibility of ensuring sufficient job tasks and performance level during normal and crisis situations.

(5) *Maintenance*: Refers to the impact on ship or platform operations as a result of improper, insufficient, or a failure to conduct adequate maintenance which is important to the day-to-day (normal operating systems) and extreme operating environments (safety & emergency operating systems). Maintenance is regarded to be the responsibility of the operating organization.

(6) *Physical/mental lapses, slip, or mistakes*: This pertains to physical or mental lapses, attention failures, memory failures and rule based mistakes which cause or contribute to failed or inadequate manned function or performance under normal or extreme operating conditions. The examination of physical and mental lapses, slips, or mistakes are for front-line crews whose tasks and job performances are inhibited during normal and crisis situations.

(7) *Violations*: Refers to intended unsafe acts such as routine and exceptional violations or acts of sabotage. Violations are addressed with regard to the front-line operating crews, the organizations who potentially influence the

decisions and actions of the crews, and the regulatory bodies which establish the guidelines for operational policies and procedures.

(8) *Morale/incentives*: Moral is the individual behavioral attributes that decrease the willingness, commitment and thoroughness in which individuals will conduct assigned tasks and functions. Incentives pertain to the differences in goals and preferences at different levels in the organization which lead to inadequate manned functions or performance. This examination addresses the morale and incentives of the front-line operating crews, the organizations who potentially influence the decisions and actions of the crews, and the regulatory bodies which establish the guidelines for operational policies and procedures.

(9) *Job design*: This encompasses the inappropriate match of personnel characteristics with job, task or role requirements, or inadequate job description that causes and contributes to failed or inadequate manned function and performance. Job design applies to the inappropriate match of individuals, the operational policies or procedures leading to inappropriate match of personnel, and regulatory policies which contribute to an accident scenario.

(10) *Regulating/policing*: The insufficient, inaccurate or failure of organizations and regulatory bodies in continually maintaining or monitoring the integrity and reliability of the operating system. Regulating and policing addresses the insufficient active participation of organization or regulatory body in maintaining the safety of the operating system.

(11) *Operating policy*: Pertains to organizational policies and procedures from top-level management to front-line operating managers which are conducive to the reduction of safety of the operating system. Organizational and management operating policies or procedures which contribute to accident scenarios through functional error types on the organizational level.

(12) *Communication & information*: Refers to the incorrect, incomplete, or failure of the transfer of information between individuals, organizations, regulators, and systems which inhibit the safety of the operating system. Insufficient communication and transfer of information can be between human and system, or individuals and parties on the organizational and regulatory level.

(13) *Manning requirements*: This embodies the inadequate manning (expertise or number of individuals) required that causes or contributes to failed or inadequate manned function or performance of the operational system. Manning decisions are maintained at the organizational and regulatory levels.

4.3 The Effects of External Operating Environments

The AHFT makes a distinction between error states and actions (see Figure 6) which contribute to accident scenarios. As shown in Figure 7, the HOE taxonomy makes a further distinction between the operating conditions (man-made or environmental) from the error causes. The reason for this distinction is to eventually examine the effects of the external operating environments on the error events and causes at the various stages in an accident sequence (see Figures 10 & 11).

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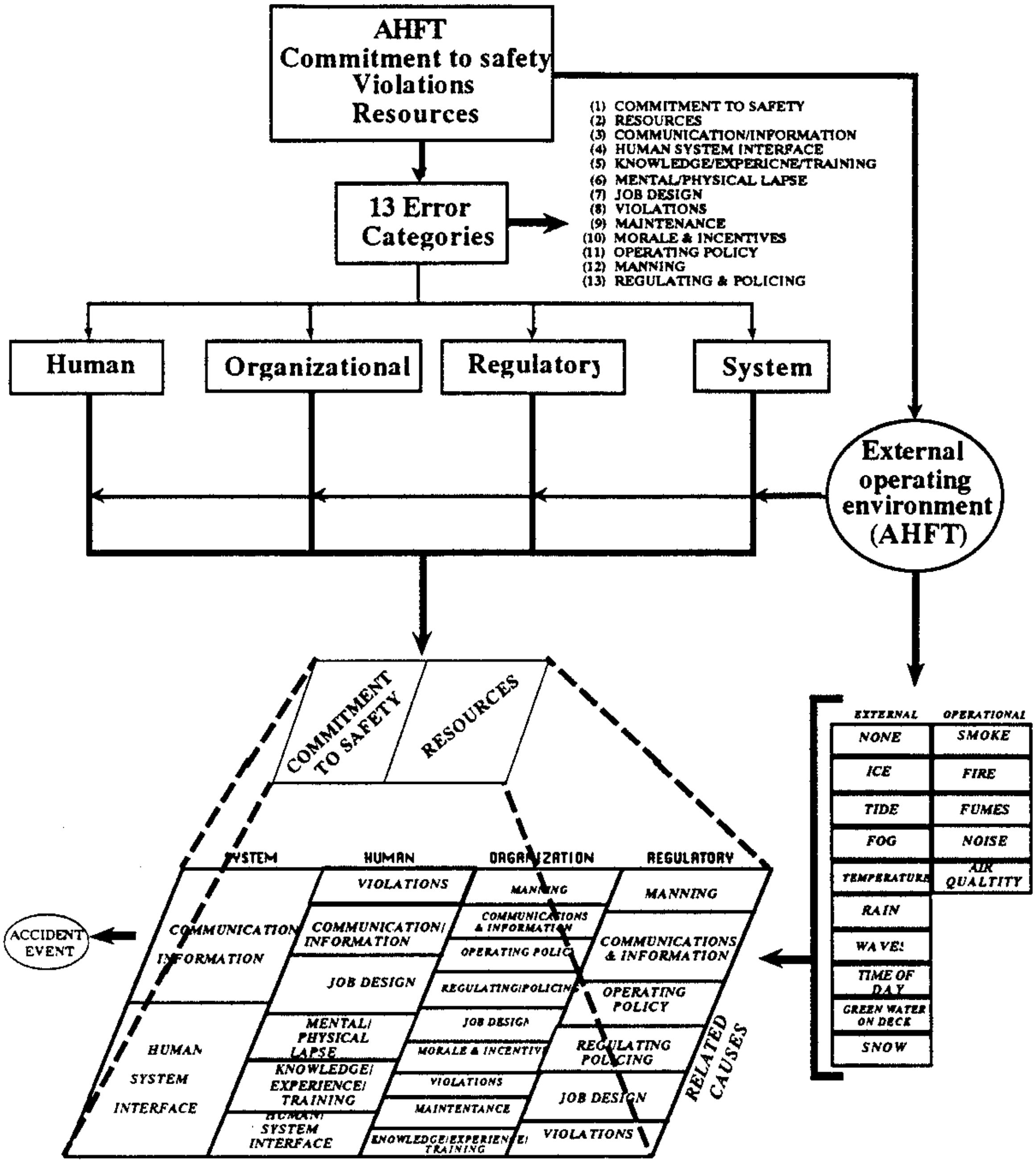

Figure 7: Breakdown of HOE taxonomy

As shown in Table II the *external operating environment* is categorized into *external* and *operational* factors. External factors are those which pertain to the external environment. Operational factors are those which are specific to the operating system.

Table II: Classification of environmental operating conditions which potentially contribute to HOE

External	Operational
None	*None*
Ice	*Smoke*
Waves	*Fire*
Time of day	*Fumes*
Tide	*Noise*
Fog	*Air quality*
Temperature	
Rain	
Green water on deck	
Snow	

4.4 Distinguishing Between Underlying, Direct & Compounding Error Causes

As shown in Figure 8-9 we establish three general contributing causes to accident scenarios:

(1) *underlying/contributing causes* (latent errors in technology, organizational, management, and regulations, or immediate underlying causes to specific error events),

(2) *direct causes* (active or accident initiating errors by front-line crews), and

(3) *compounding causes* (latent errors in organizations, regulations, technological systems, etc.).

For example, Figure 8 and 9 demonstrates the basic events of a potential tanker grounding and a platform gas production fire respectively. Each of the events are influenced by particular HOE factors. Figure 8 shows the three primary events of a vessel grounding: (1) the vessel deviates from the pre-determined traffic separation scheme (underlying or contributing event), (2) the vessel runs aground (direct event), and (3) the vessel is pulled of the rocks after the grounding (compounding event). Similarly, Figure 9 demonstrates the primary events surrounding the loss of life and platform: (1) decision to conduct maintenance and production simultaneously (underlying or contributing event), (2) explosions & fires (direct event), and (3) loss of life and platform (compounding event).

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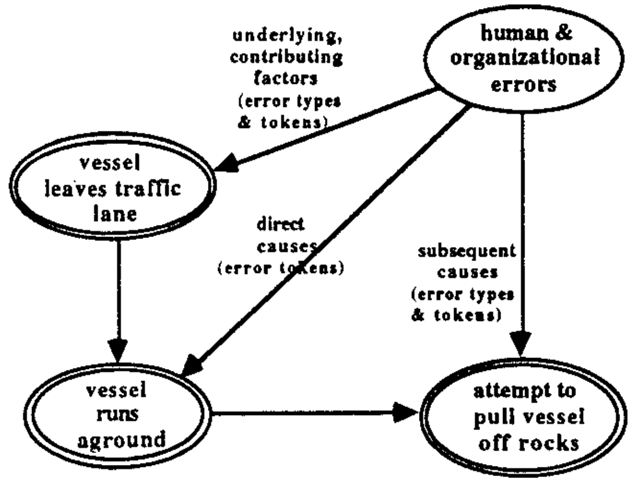

Figure 8: Accident events dependencies on HOE factors for tanker grounding

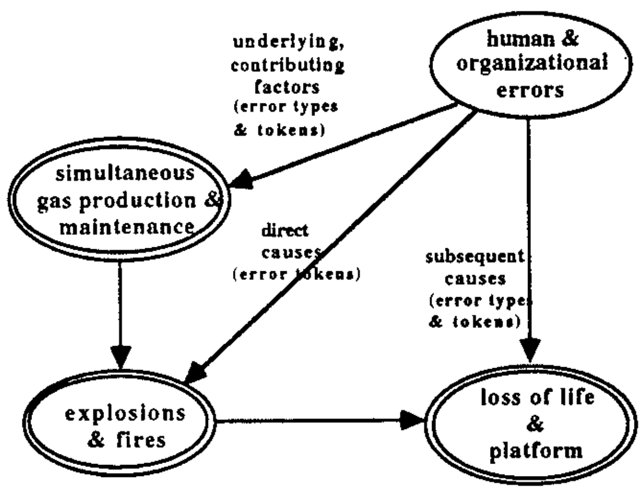

Figure 9: Accident events dependencies on HOE factors for platform gas production fire

5.0 QUALITATIVE APPLICATION OF HOE TAXONOMY

The following are two examples of the applications of the HOE taxonomy on post-mortem study analyses. The models incorporate the underlying & contributing, direct, and compounding causes to the accident scenarios. This qualitative modeling procedure is a precursor for the quantitative post-mortem models (*Exxon Valdez* and *Piper Alpha*) to be conducted for the HOE project (see § 2.0). The detailed modeling and quantitative analyses of both the *Exxon Valdez* and *Piper Alpha* are in the concluding stages of development and will be subject of a future report.

The following sections describe the HOE factors involved in the *Exxon Valdez* and *Piper Alpha* disasters using the taxonomy framework described in Chapter 4. Preliminary studies have identified the HOE factors contributing to the accident scenarios [Roberts & Moore, 1992; Moore, 1992; Keeble, 1991; National Transportation Safety Board, 1990; Davidson, 1990; Paté-Cornell, 1992; United Kingdom Department of Energy, 1990]; Petrie Report, 1990].

The methodology used in this modeling procedure separates the modeling into *events*, *causes*, and *conditions* and is organized in Steps 1-6 below. This simplified procedure assists the modeler in identifying the correlation between accident events, causes and the external operating conditions.

Step 1

Establish a set of primary contributing & underlying, direct, and compounding events leading to the accident scenario.

Step 2

Determine the HOE causes leading to each of the primary events.

Step 3

Establish the contribution of the external operating conditions to each of the accident events and HOE causes.

Step 4

Does the model capture sufficient detail of the accident scenario for further analysis to fit the preferences of the user?

Step 5

If yes, perform qualitative and quantitative analyses on the correlation of events, causes, and conditions established in Steps 1-3.

Step 6

If no, repeat Steps 1-6 by first expanding the set of accident events.

The primary goal is to establish the error types and how they manifest into error tokens to create accident scenarios. The modeler may wish to examine the specific events surrounding the accident by examining the immediate contributing and underlying causes (i.e. *Exxon Valdez* leaving the traffic separation scheme to avoid the ice floes). From this analysis the error types can be traced by the specific actions of the front-line operating crews (error tokens). On the other hand, the modeler may wish to examine the general operating procedure (error types) which lead to the accident scenarios (i.e. *Piper Alpha* conducting critical maintenance and producing simultaneously) and determine the chain of specific errors by front-line operating crews (error tokens).

5.1 The grounding of *Exxon Valdez*

Figure 10 shows the influence of causes and conditions upon the events surrounding the grounding of *Exxon Valdez.* The primary set of accident events in the grounding of *Exxon Valdez* and their related causes are summarized as follows [Moore, 1992]:

Underlying/contributing factors

Event: *Exxon Valdez* deviates from the outbound traffic separation scheme (TSS) to avoid the ice floe in the lane.

Causes: The deviation of from the TSS was not an isolated incident though was not recommended by either the operators nor the USCG. At the time of the grounding there had been a reduction of billets at the USCG Marine Safety Office in Valdez. On the night of the grounding the vessel traffic center (VTC) crew had not established *Exxon Valdez* on the radar nor kept in radio communication after the vessel left the Valdez Narrows.

As the vessel deviated from the lane it was placed on automatic pilot (it is questionable as to whether the auto pilot was on until just before the grounding). The master left the bridge leaving only the third mate in command which is in violation of Exxon Shipping operating policy. At the time of the grounding, Exxon was in the process of determining how to reduce the crew sizes aboard the vessels even though crews frequently are excessively fatigued and overworked. The company had conducted no studies on the human effects of reducing crew sizes.

Conditions: Ice floe conditions in the outbound lane of the TSS was a precursor to the decision to deviate from the TSS.

Direct factors

Event: The vessel does not return to the TSS and grounds on Bligh Reef.

Causes: The USCG had had problems with the radar system in Prince William Sound at the time of the grounding. It is questionable as to whether the VTS personnel could properly monitor the *Exxon Valdez* on the radar. Though no radar communication may have been possible, the vessel and VTS personnel had not kept in radio communication to determine the track of *Exxon Valdez.*

It is speculated that the third mate was unable to determine the location of the vessel just before the grounding. His lack of knowledge, training, and experience under these operating conditions had made it difficult to make proper navigation decisions.

Conditions: The time was approximately midnight at the height of changes of watch.

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Compounding factors

Event: Captain Joseph Hazelwood, the master of *Exxon Valdez*, attempts to lodge or dislodge the vessel from Bligh Reef resulting in the compounded loss of cargo.

Cause: Captain Hazelwood may have attempted to push the vessel onto the reef to keep the vessel from capsizing. This may have been a violation of law to limit the discharge of cargo into the water.

Conditions: At the time of the grounding the tide was dropping. This may have led to the decision to stabilize the vessel on the rocks and keep from capsizing.

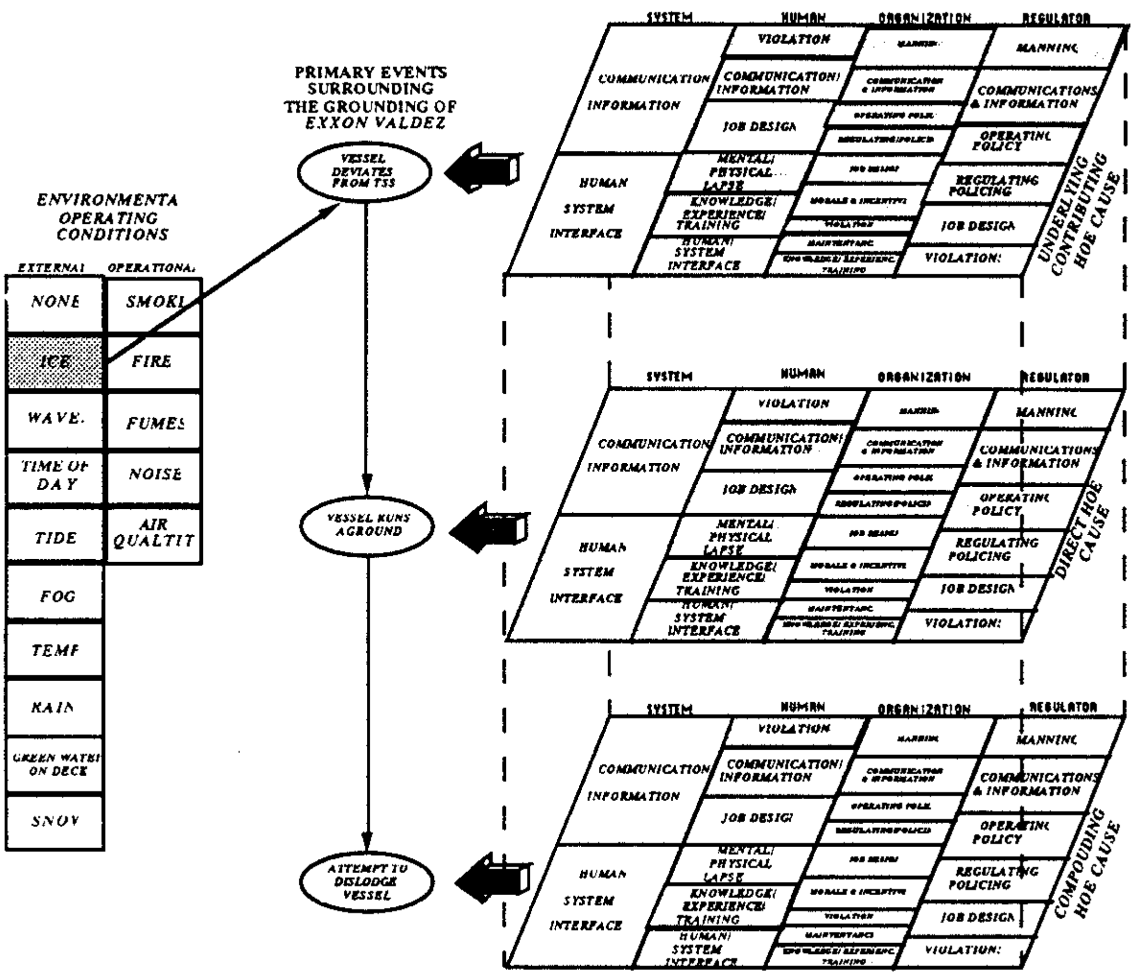

Figure 10: HOE influences on the events surrounding the grounding of *Exxon Valdez*

5.2 The *Piper Alpha* disaster

Figure 11 is a schematic diagram of the influence of causes and conditions upon the events surrounding the *Piper Alpha* disaster. The primary set of accident events of the *Piper Alpha* disaster and their related causes are summarized as follows [Paté-Cornell, 1992]:

Underlying/contributing factors

Event: Decision to conduct critical maintenance and produce simultaneously.

Causes: Occidental management had decided to conduct maintenance and produce simultaneously even though the maintenance would eliminate various safety systems. This displays a lack of commitment to safety by the operator while focusing on production with little regard for a safe production process.

Conditions: Night crew change, wind blowing across platform in direction of quarters, production at highest possible level.

Direct factors

Event: Initial explosion in Module C resulting from a leak in condensate pump A at a blind flange assembly leads to a chain of explosions, fires, fumes and smoke engulfing the platform in a matter of seconds.

Causes: Maintenance crews in Module C had not informed control room operators of the operational status of the condensate pumps. The blind flange assembly on condensate pump A was improperly done. There was little warning as to the escalating conditions in Module C prior to the initial explosion. The emergency gas detection system had been partially decommissioned or were not operating.

Conditions: Initial explosions occurred at approximately midnight.

Compounding factors

Event: The death of 167 men and the total loss of the platform.

Cause: The events succeeding the initial explosions and fires were compounded by the lack of available escape routes, a lack of experience, training, and knowledge of the operating personnel (only 26 men were permanently stationed on the platform at the time of the disaster). The emergency lighting, deluge, and communication systems were completely inoperable moments after the initial explosion. There were no orders given to evacuate the platform.

The *MS Tharos* role in controlling the fire and rescuing personnel was limited though the semi-submersible was fully equipped to handle offshore fires.

At the time of the accident, the *Claymore* and *Tartan* platforms had been piping high-pressure gas to *Piper Alpha*. The failure of the offshore installation managers of *Tartan* and *Claymore* to immediately shut down production operations led to further loss of life and platform. Though the platform had been cited for a number of safety violations by the Department of Energy, few changes had been implemented.

Conditions: Smoke, fire, and fumes engulf the platform making it virtually impossible for control of the fire or escape of personnel from the accommodations unit where 84 men die.

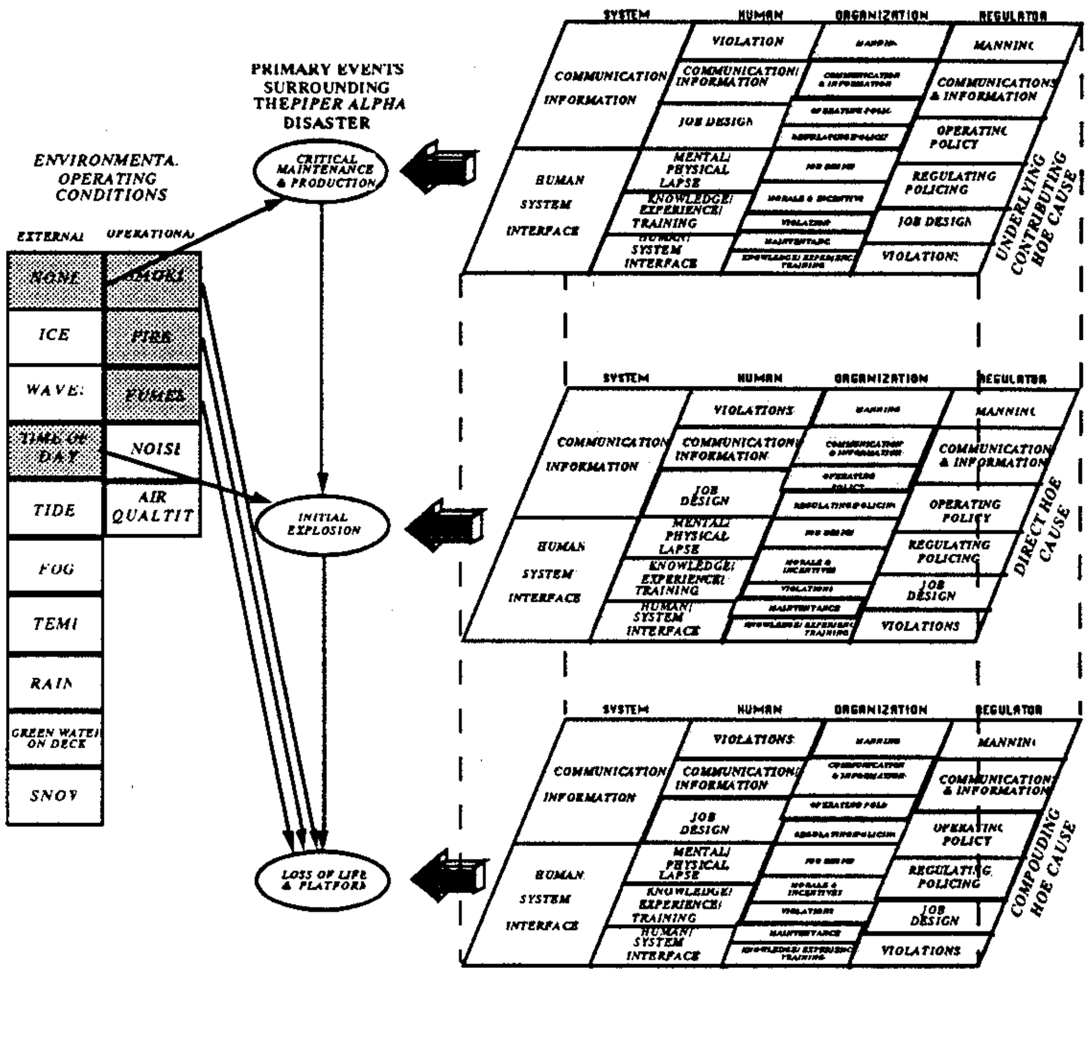

Figure 11: HOE influences on the events surrounding the *Piper Alpha* disaster

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6.0 CONCLUSIONS

The review of current human and organizational taxonomies yields that there exists no standardized, hierarchically organized, concept or format for identifying human factor casualty data to identify and link underlying, direct, and compounding causes that shape human behaviors and actions responsible for accident sequences. The HOE project taxonomy will be instrumental in the qualitative and quantitative analyses of both post-mortem studies and existing operations to examine underlying and contributing, direct and compounding errors in accident scenarios. The importance of the taxonomy is to capture the primary contributing causes of marine casualties and relate them directly to the events in the accident chain.

Following reports will examine in detail the influences of accident causes and conditions upon the events surrounding the *Exxon Valdez* and *Piper Alpha* disasters. From this analysis modelers can formulate a classes of accident scenarios and evaluate alternatives for human and organizational error management.

7.0 ACKNOWLEDGMENTS

This paper is funded in part by a grant form the National Sea Grant College Program, National Oceanic and Atmospheric Administration, Department of Commerce, under grant number NA89AA-D-SG138, project number R/OE-17 through the California Sea Grant College, and in part by the California State Resources Agency. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies. The U.S. Government is authorized to reproduce and distribute for government purposes.

This work also has been sponsored in part by Chevron Research & Technology Company and Chevron Shipping Company, Amoco Production Company and Amoco Transport Company, Unocal Corporation, the California State Lands Commission, the U.S. Coast Guard, the U.S. Minerals Management Service, and the American Bureau of Shipping. The support and guidance of these sponsors is gratefully acknowledged.

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